EUV Actinic Mask Imaging with the SEMATECH Berkeley *Actinic Inspection Tool* (AIT)
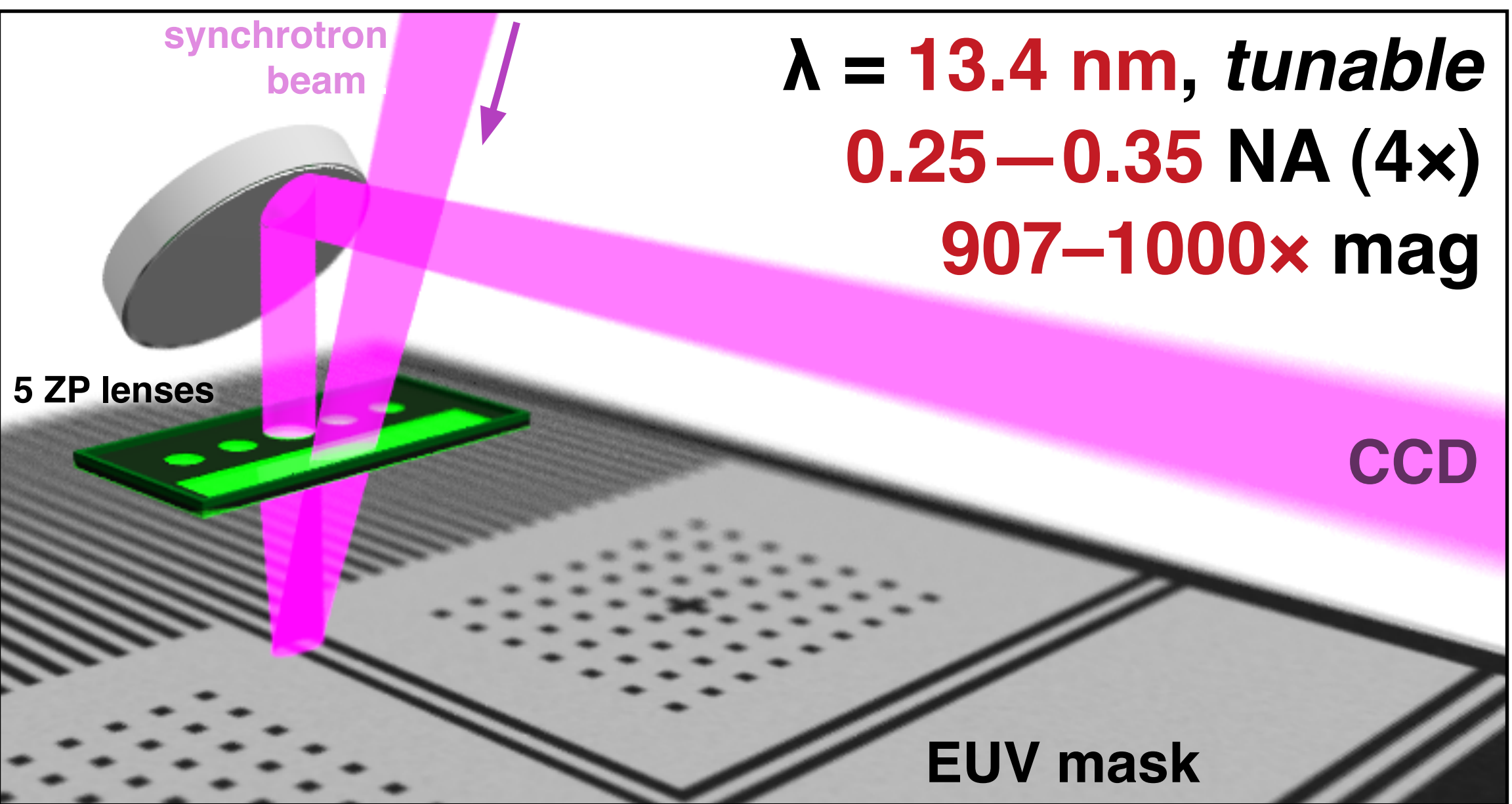## *A pathway to 8 nm EUVL and beyond*

K. A. Goldberg, I. Mochi, N. Smith, S. Rekawa, J. Macdougall, P. Naulleau
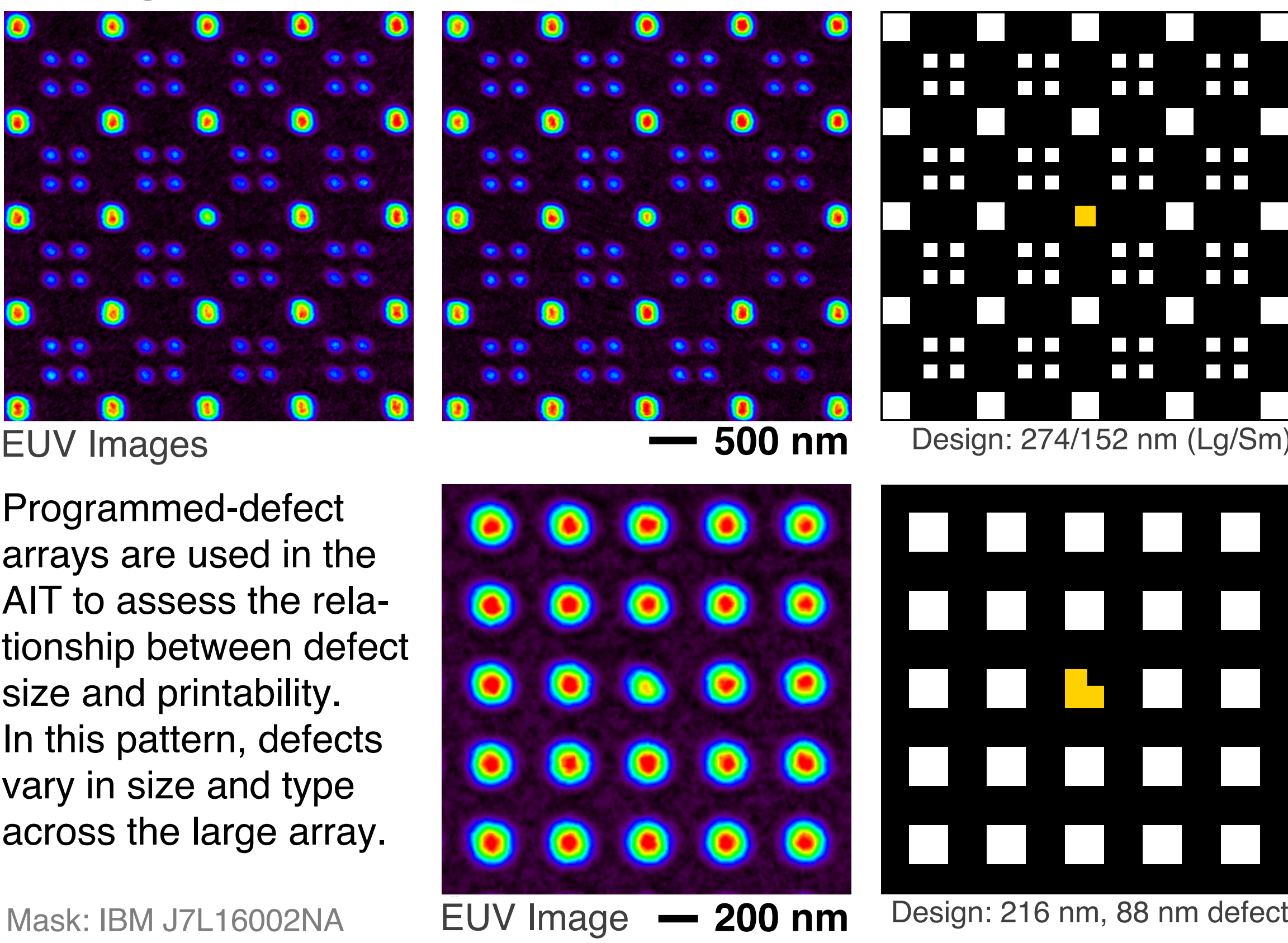*Center for X-Ray Optics, Lawrence Berkeley National Laboratory*

SEMATECH · CXRO THE CENTER FOR X-RAY OPTICS · BERKELEY LAB

The current *AIT*

AIT Imaging Lens Schematic

λ = 13.4 nm, *tunable*
0.25—0.35 NA (4×)
907–1000× mag

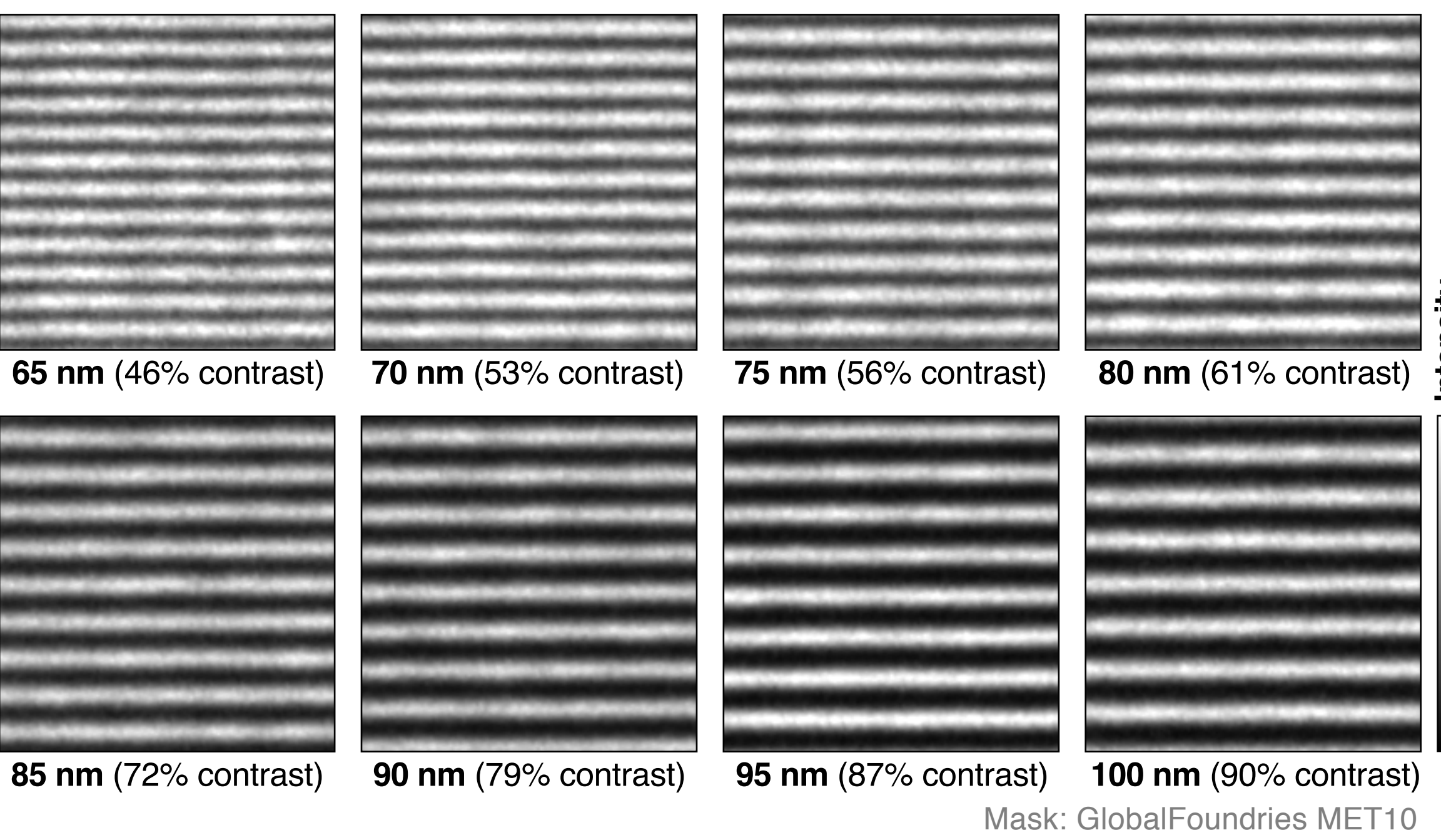synchrotron beam · 5 ZP lenses · CCD · EUV mask

The AIT is the world's first Fresnel zoneplate microscope with an array of interchangeable, high-magnification lenses—*made by CXRO's Nanowriter.*
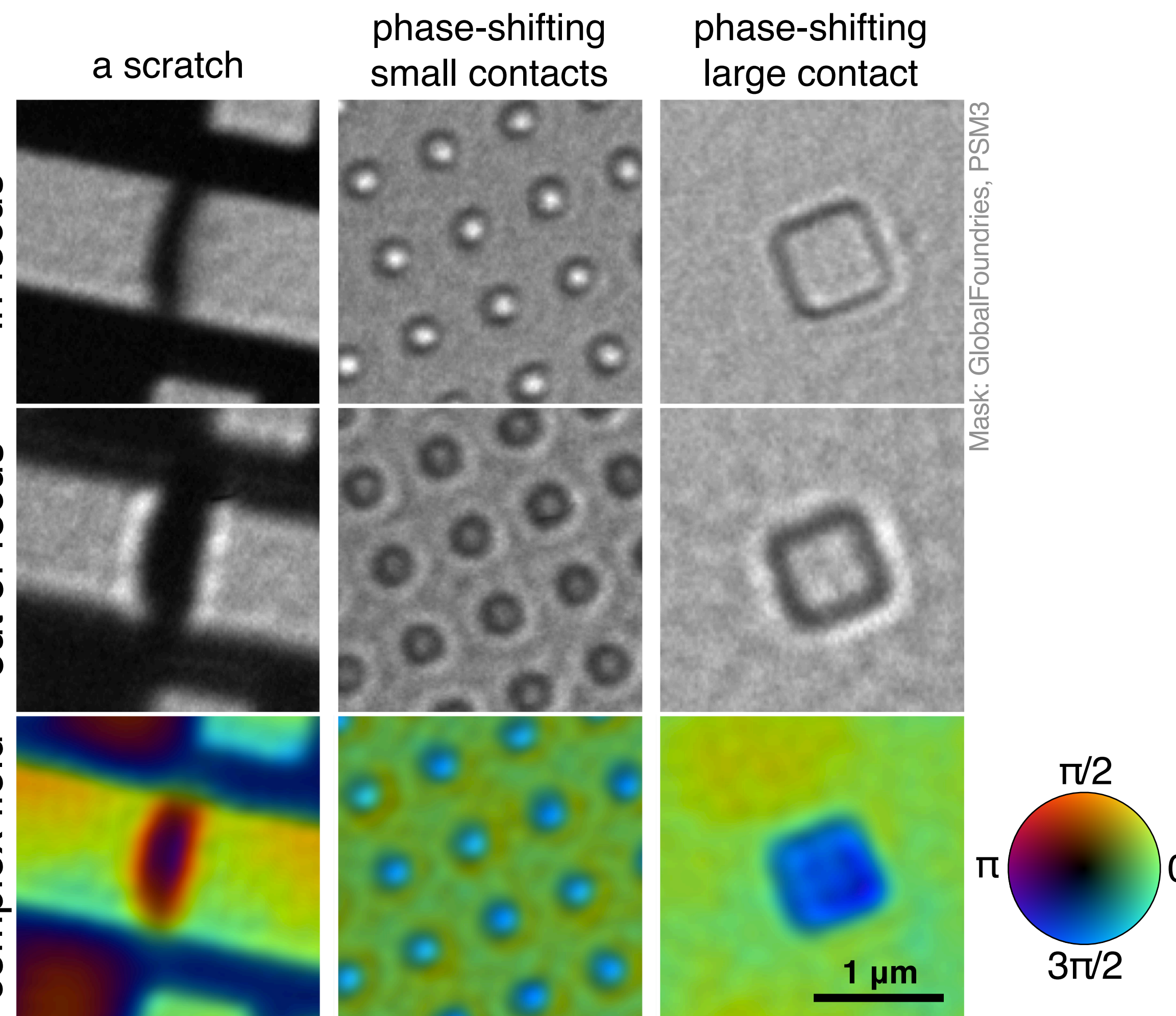
Programmed Defects

EUV Images — 500 nm · Design: 274/152 nm (Lg/Sm)

Programmed-defect arrays are used in the AIT to assess the relationship between defect size and printability. In this pattern, defects vary in size and type across the large array.

Mask: IBM J7L16002NA

EUV Image — 200 nm · Design: 216 nm, 88 nm defect

Resolution Tests

65 nm (46% contrast) · 70 nm (53% contrast) · 75 nm (56% contrast) · 80 nm (61% contrast)

85 nm (72% contrast) · 90 nm (79% contrast) · 95 nm (87% contrast) · 100 nm (90% contrast)
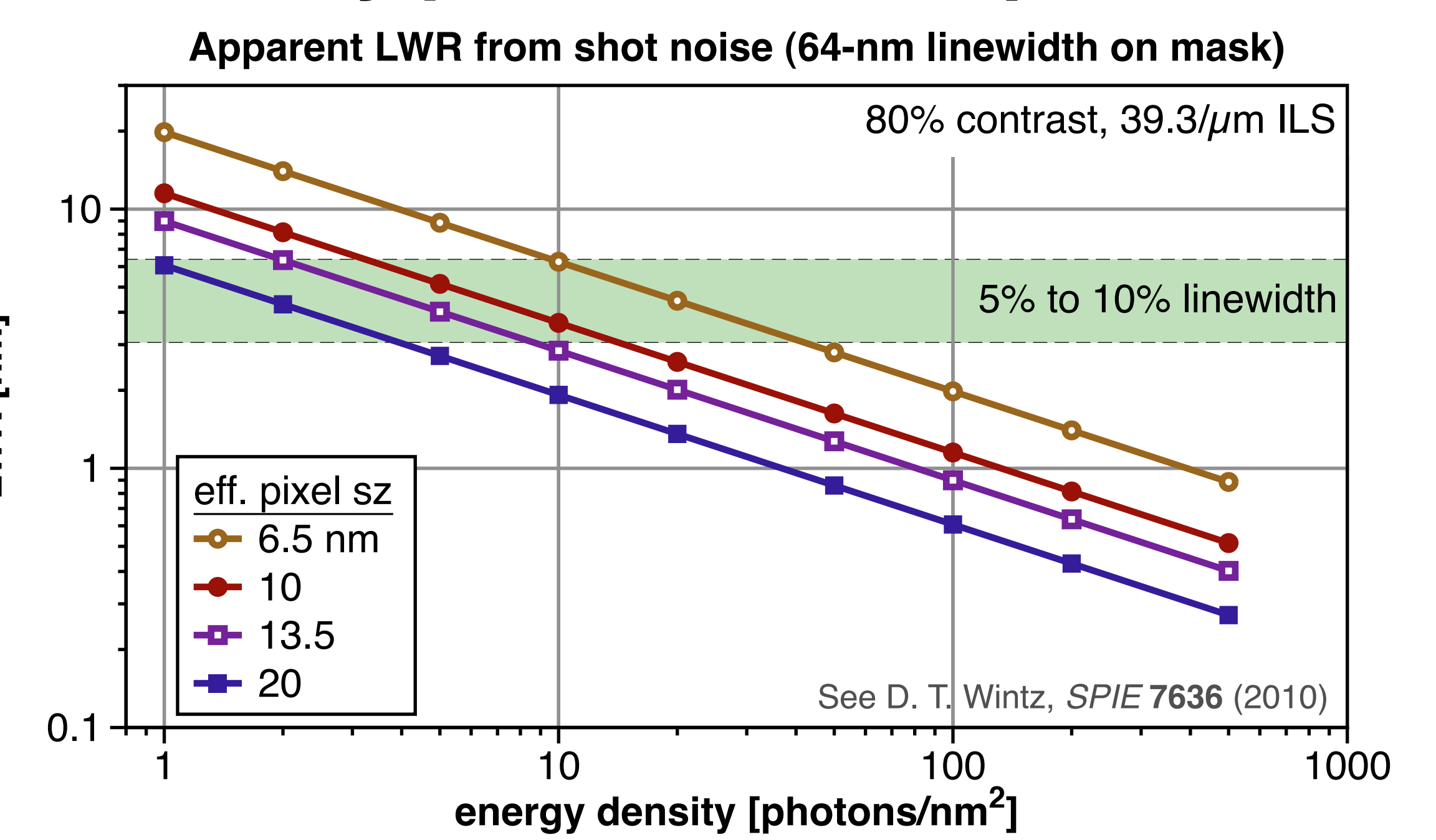
Mask: GlobalFoundries MET10

Line size (half-pitch) and Contrast @ 0.35 NA (4×)
In practice, these mask features are printed with 4× reduction.

We measure new mask architectures and material combinations that can display very different line properties—especially for small features.
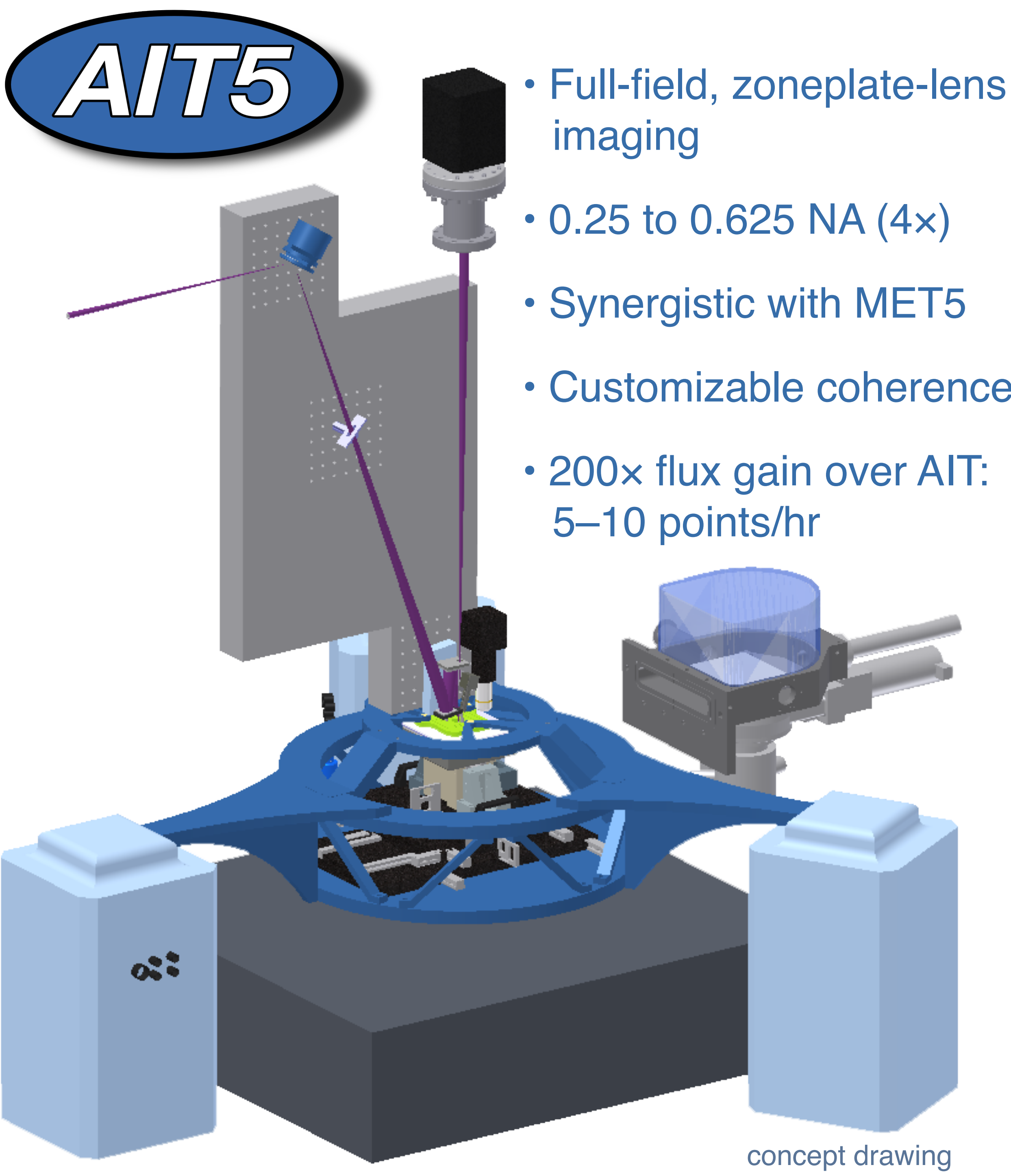
Measuring the Aerial Image Phase

a scratch · phase-shifting small contacts · phase-shifting large contact

in focus · out of focus · complex field

Mask: GlobalFoundries, PSM3

1 µm

We recently implemented a powerful algorithm to reconstruct the complex aerial image field given multiple through-focus images.

The proposed *AIT5*
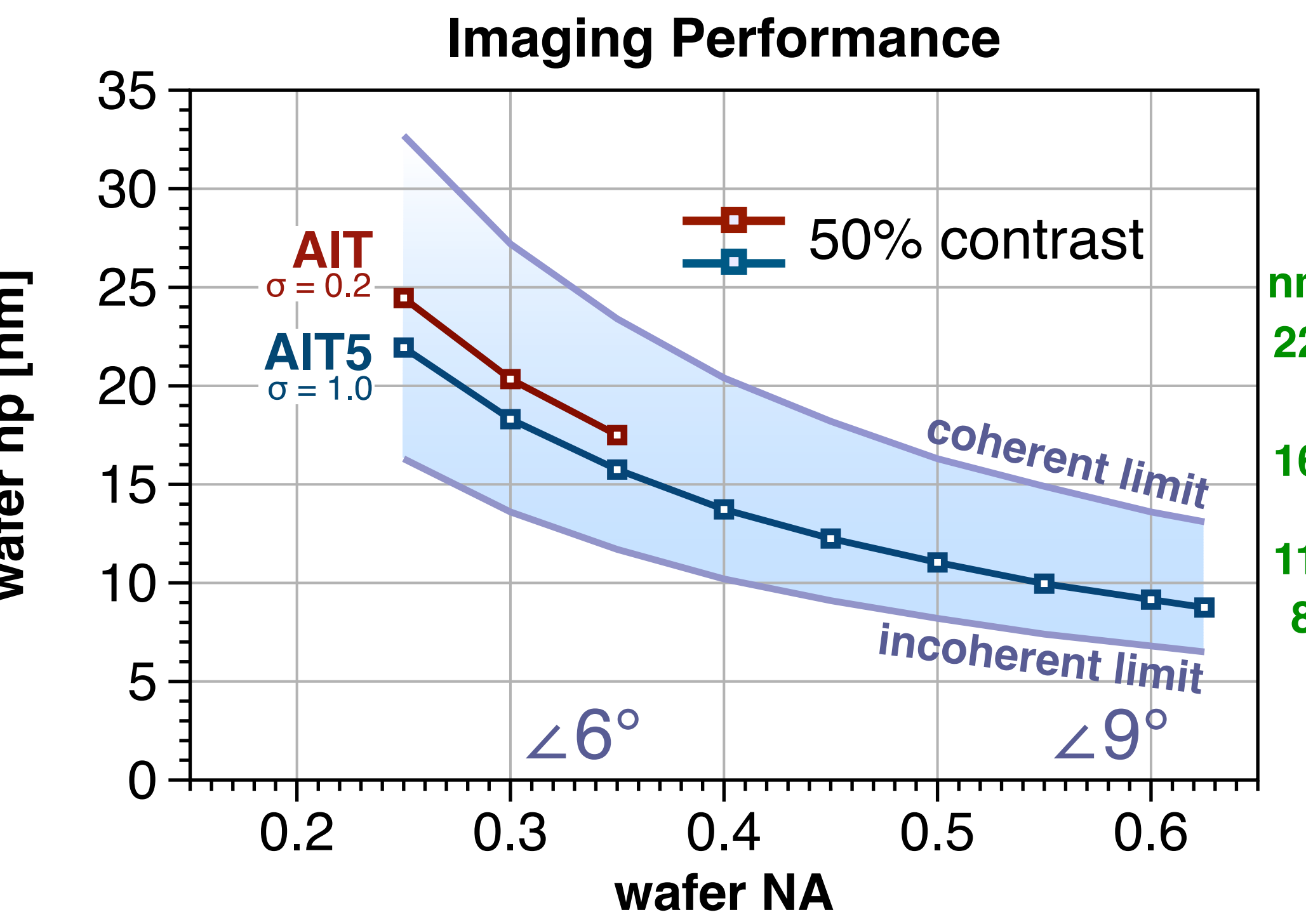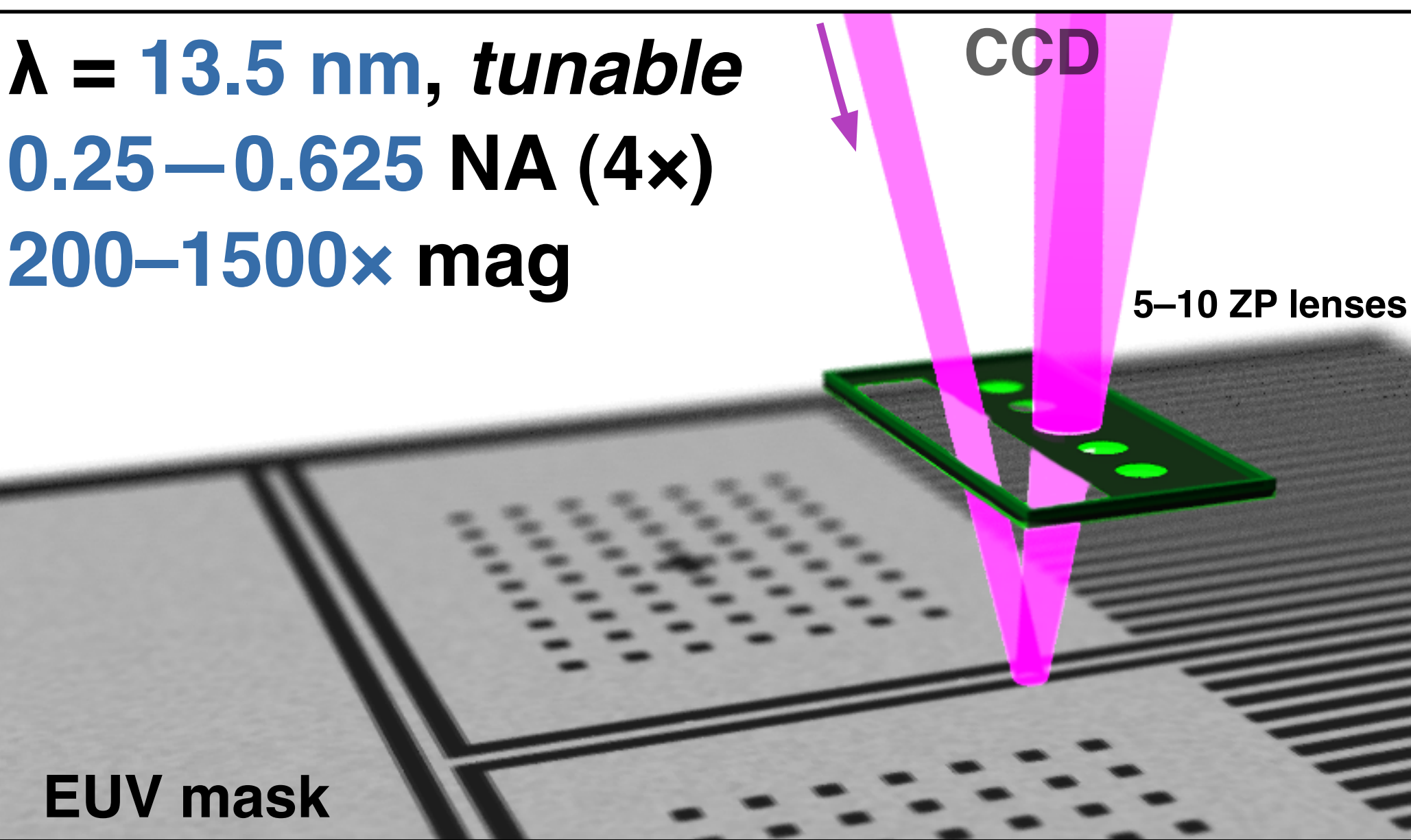
AIT5

concept drawing

- Full-field, zoneplate-lens imaging
- 0.25 to 0.625 NA (4×)
- Synergistic with MET5
- Customizable coherence
- 200× flux gain over AIT: 5–10 points/hr

AIT5 Imaging Lens Schematic

λ = 13.5 nm, *tunable*
0.25—0.625 NA (4×)
200–1500× mag

CCD · 5–10 ZP lenses · EUV mask

Imaging Performance

AIT σ = 0.2 · AIT5 σ = 1.0 · 50% contrast · coherent limit · incoherent limit

wafer hp [nm] · nm 22 16 11 8 · $\angle6°$ · $\angle9°$ · wafer NA

AIT5 Summary of Advantages

Optics and illumination
- Zoneplate lens array (variable NA)
- Coherence and uniformity scanners

Navigation
- Integrated visible-light microscope
- Non-contact mask XYZ stage

Efficiency
- Streamlined design for high throughput

Maintenance
- Accessible architecture
- Straight beam path to CCD

Synchrotron Source
- Clean, reliable, no cost

LBNL Engineering
- Built by the same team that runs AIT and MET

	AIT	AIT5
Why?	Actinic imaging for essential early learning	Advanced research, to 8-nm; true aerial image testing
mask stage	*xyθz (hard navigation)*	*xyz*
zoneplate stage	*xyθz*, decoupled	*xyz*, coupled to mask stage
mask e-chuck	non-functional θ alignment problems	working chuck, kinematic loading
vibration isolation	mask surface touching greatly slows work	active isolation, coupled stages
***in situ* vis. microscope**	not available	integrated
illumination angle & σ	$\angle6°$ & $\sigma \leq 0.2$	$\angle6–10°$ & $\sigma \leq 1$
max NA (4x), resolution	0.35, 17.5 nm (wafer)	**0.625** (or higher), 6.5 nm (wafer)
flux, exposure time	low flux, 45 sec exp.	**200× AIT**, 1 sec w/ 2x SNR
illumination uniformity	gradients	optimized, flat
system alignment	very challenging	simplified with *in situ* detectors, pupil-fill monitor
mask loading / handling	manual	SMIF pod / automatic
operators	trained Ph.D.s	technician

How many photons are required?

Apparent LWR from shot noise (64-nm linewidth on mask)

80% contrast, 39.3/µm ILS

5% to 10% linewidth

LWR [nm]

eff. pixel sz: 6.5 nm · 10 · 13.5 · 20

energy density [photons/nm²]

See D. T. Wintz, *SPIE* **7636** (2010)

High wavefront quality can be achieved

Strehl Ratio · RMS WFE [λ]
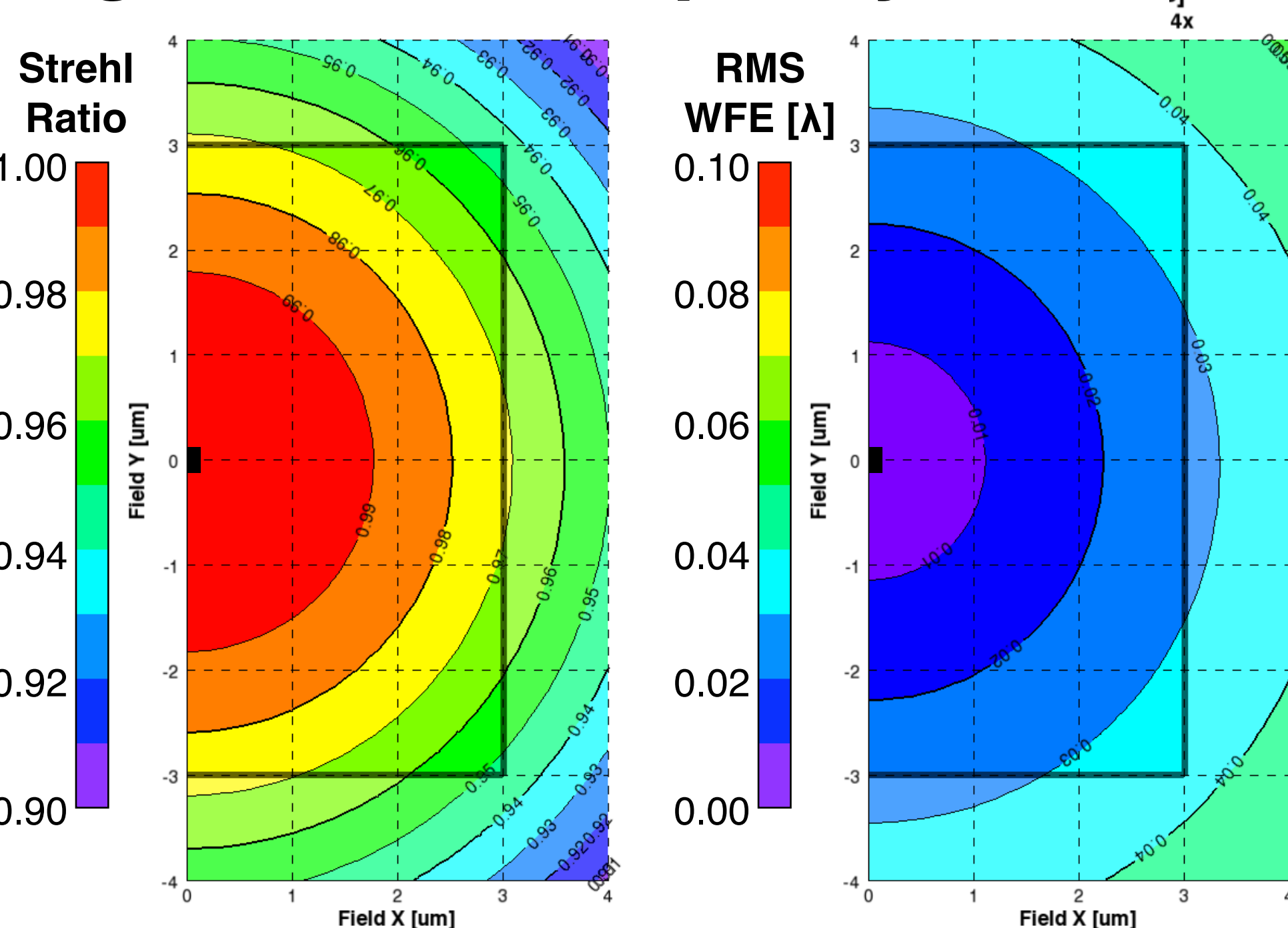
Modeling predicts excellent wavefront quality, CD uniformity, and minimal HV bias across a 6-µm-wide *sweet spot* at 0.3 NA 4×. The diameter of the aberration-corrected area varies with the ZP focal length and NA.

Lossless coherence control

mask-side pupil (angle space) fill pattern · high coherence · annular

off-axis monopole · off-axis monopole · x-dipole